LATE CENOZOIC GEOLOGY OF McGEE MOUNTAIN MONO COUNTY, CALIFORNIA

BY

WILLIAM C. PUTNAM

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ABSTRACT

McGee Mountain, in the Sierra Nevada of eastern California, is an important place for reaching an understanding of the Late Cenozoic events in the history of the range. Morainal deposits of four glacial stages which were described by Blackwelder on the eastern slope of the mountains are present here; from oldest to youngest, they are: McGee, Sherwin, Tahoe, and Tioga.

Till of the McGee glacial stage is preserved on an upland shoulder of the mountain at altitudes ranging from 9,840 to 10,880 feet. This deposit has been elevated approximately 4,000 feet to its present position by faulting and warping since deposition.

The Sherwin, Tahoe, and Tioga moraines were deposited in canyons excavated 2,400 to 2,800 feet following the McGee glacial stage. They are cut by necessarily younger faults whose recency indicates that the uplift of the range is still in progress.

Evidence at McGee Mountain corroborates the conclusions of Axelrod and Ting, based on work elsewhere in the range, that the principal uplift of the Sierra Nevada occurred in the Pleistocene, and that the mountains do not have the antiquity postulated by Matthes.

INTRODUCTION

General Statement

McGee Mountain[1] makes a boldly projecting, nearly flat-topped salient of the Sierra Nevada in eastern California. To the traveler on U. S. Highway 395, which hugs its base, the chief impressions of the mountain are likely to be its barrenness and the uniform inclination of its slopes. Viewed from a distance, these slopes appear to rise at a nearly constant angle of about 25° from the nearly level, alluviated floor of Long Valley up to the plateaulike summit, whose average inclination eastward is about 5°. The mountain stands as a monolithic mass whose flanks are scored by the most trivial of ravines when their dimensions are compared with the imposing bulk of the mountain. In fact, it is a mountain singularly lacking in any aesthetic appeal when compared with its more resplendent neighbors in the immediately adjacent High Sierra.

The blocklike form of the mountain is a product of its gently undulating summit, nearly constantly inclined eastern escarpment, and the abrupt fashion in which the entire mass is cut off by deep canyons, to the northwest by Convict Creek[2] and to the southeast by McGee Creek.

McGee Mountain has other claims to recognition beyond its singularly cheerless appearance, or its strategic location at a salient of the Sierra Nevada where the trend of the range changes from essentially southeast-northwest to nearly east-

[1] McGee Mountain is not named for W J McGee, redoubtable figure of early Western geomorphology, but for the McGee family, a formidable clan of pioneers, Indian-fighters, and cattlemen, who settled in Long Valley in 1866.

[2] Convict Creek and Convict Lake take their names from a colorful episode in 1871 when six convicts, escaped from the Nevada State Prison at Carson City, elected to make their stand here. In the ensuing gun fight, Robert Morrison, a member of the posse, was killed, and the 12,268-foot peak overlooking the lake bears his name. The convicts escaped, although later three were captured south of here and two were lynched near Bishop (Schumacher *et al.*, 1959, p. 8).

west. The truly noteworthy feature of McGee Mountain is that on its summit, and in the canyons marginal to the mountain, are preserved the most complete record of the glacial succession in the east-central Sierra Nevada. Part of this record is clearly visible to the most casual observer driving along the highway. This is the series of great lateral moraines nested inside one another at the mouths of the deep canyons flanking the mountain. These moraines are most conspicuously developed along Convict Creek, but they are impressive elements of the terrain at the mouth of McGee Canyon as well.

Less apparent, but perhaps of greater scientific interest, are the discontinuous patches of till high up on the summit ridges of the mountain. The white boulders can be seen from afar, especially from the north, as a tattered blanket only partly covering the somber, reddish-brown, metasedimentary rocks on which they rest. These high-level, boulder-studded deposits are the McGee till, and it is with their relationship to the later glacial moraines, as well as to the tectonic and erosional history of this part of the Sierra Nevada, that this paper is concerned.

Previous Work

Investigations of the glacial record of the Sierra Nevada have been carried on with varying degrees of thoroughness over a long period. The nature and quality of the earlier studies is well summarized by Eliot Blackwelder (1931), who pays a deserved tribute to the truly pioneer endeavors of W. D. Johnson in 1905, 1906, and 1907. As Blackwelder points out, Johnson had recognized the existence of three glacial stages at this early date, but because his death intervened, his findings were never published. Blackwelder's paper is the fundamental source for any student of eastern Sierra Nevada glaciation. He distinguished and named four glacial stages for the region: in sequence from oldest to youngest they are, McGee, Sherwin, Tahoe, and Tioga.

The type locality for the McGee glacial stage is the summit plateau of McGee Mountain, on whose surface are scattered discontinuous patches of till consisting of granitic boulders and hornfels fragments. A major purpose of this paper is to present the results of a field investigation of the McGee till more detailed than Blackwelder's and to demonstrate the relationship of the McGee to the younger glacial deposits, all of which are present in the mouths of the canyons directly below.

Studies other than Blackwelder's have been concerned with the glacial history elsewhere in the Sierra Nevada. Among these is the deservedly renowned work of F. E. Matthes (1930) on the former glaciers of the Yosemite Valley on the western slope of the Sierra Nevada. A significant difference between Matthes' work and Blackwelder's is that the former found evidence for only three glacial stages on the western side of the range, while the latter demonstrated the existence of four on the eastern flank. This "difference" is more apparent than real because Matthes did not divide the Wisconsin, the latest glacial stage he recognized, into two parts, whereas Blackwelder did, naming them the Tahoe and Tioga.

Other investigations that bear on the local geology, or on the Sierran glacial succession, are cited at appropriate places in this paper. Of special interest are those of C. M. Gilbert (1938, 1941) on the volcanic record and the structural

pattern of a broad domain east of the Sierra Nevada. The general geology of the Mt. Morrison quadrangle, which includes McGee Mountain within its boundaries, was mapped some years ago for the U. S. Geological Survey by C. D. Rinehart and D. C. Ross, and I hope very much that their findings will be published without too long a delay.

The peculiar pattern of the morainal loops at the mouths of Convict and McGee canyons were studied by J. E. Kesseli (1941), and are described when these moraines are discussed.

Acknowledgments

It is indeed a pleasure to give credit to the many people who have helped or have given advice on many different aspects of this investigation. I am especially indebted to my colleagues, D. I. Axelrod and Cordell Durrell, who gave many fruitful and pungent criticisms on this and related Sierran problems over the years. I am glad to acknowledge the help of P. C. Bateman, C. D. Rinehart, and D. C. Ross, all of the U. S. Geological Survey, in arriving at an understanding of the regional Sierran geology. I am especially obligated to Mrs. Peter Kurtz for her skill and care in drafting the maps and figure. I am also happy to acknowledge my debt to Professors J. E. Kesseli, of the University of California, and Eliot Blackwelder, of Stanford University, for the interest they aroused and the encouragement they gave me through the years in my concern with problems of Sierran geology.

GEOGRAPHY

Regional Setting

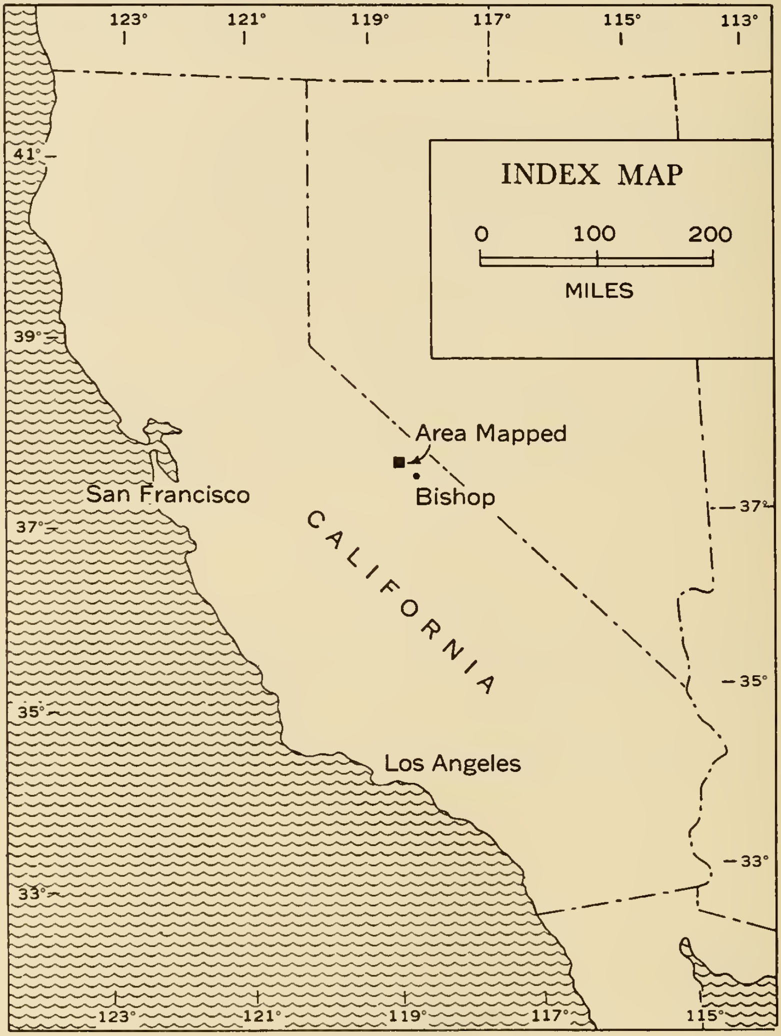
McGee Mountain stands as a boldly eastward-facing salient of the Sierran escarpment. As the index map (map 2) shows, it is about 300 miles north of Los Angeles, from where it can be reached by U. S. Highway 395. The small area mapped for this study has within it parts of two major terrain units: (1) Long Valley, which in turn is part of the Great Basin, and (2) the Sierra Nevada (location map, map 3).

LONG VALLEY

Only the extreme southwestern part of this elongate trough at the base of the Sierra Nevada is within the area mapped. The trough itself is about 15 miles long, and averages about 5 miles wide. It is almost mountain-encircled, with the Sierra Nevada forming the southern wall and the Glass Mountain Range the northern. On the east, the Long Valley basin is partly closed by the Benton Range, and on the southeast the valley is walled off by a low plateau of rhyolitic pumice and welded tuff which is incised by the two deep gorges cut by Rock Creek and the Owens River. The latter serves as the outlet of Long Valley, and it appears to have achieved this dominant role through headward growth and capture (Putnam, 1960*a*).

In the later part of the Pleistocene, very possibly during the Tahoe glacial stage, Long Valley trough was occupied by a large lake, perhaps as much as 400 feet deep, to which Mayo (1934*a*) gave the name of Long Valley Lake. Shorelines are conspicuous at the south end of Long Valley where they have been cut in rhyolite

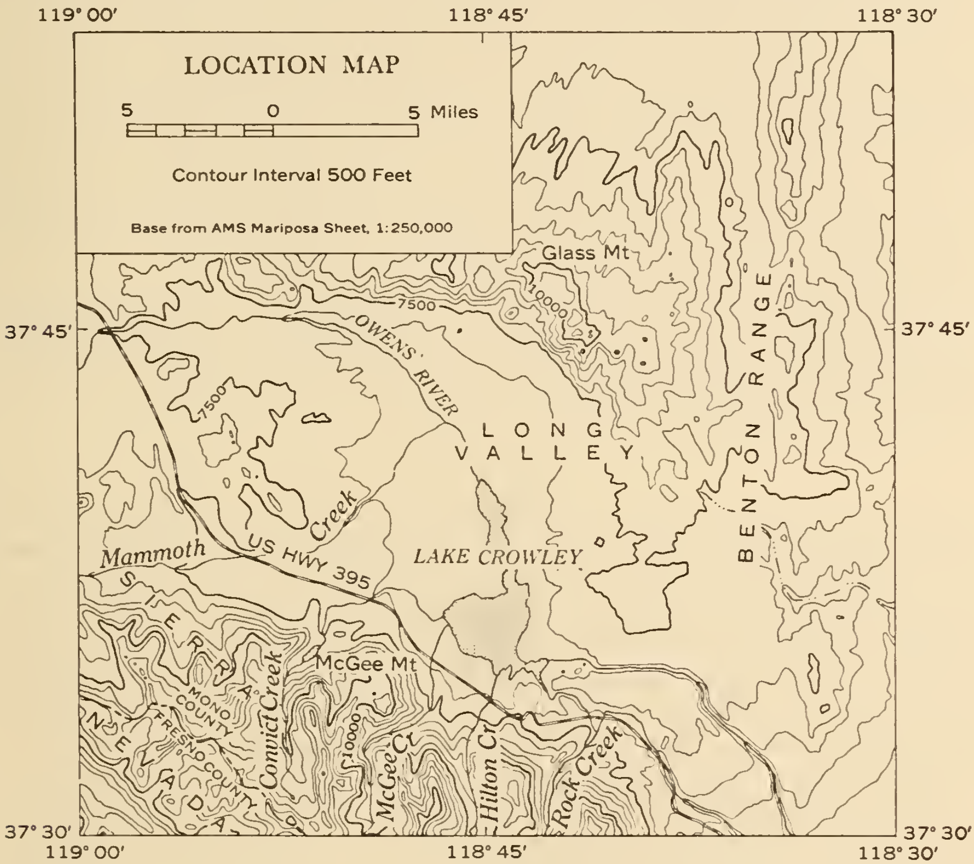
pumice and tuff, as well as along the eastern side of the valley, which probably was then, as now, the leeward side of the basin. That these terraces have been warped by diastrophism in the Late Pleistocene is shown by differing altitudes of the highest terrace: 7,000 feet at the south end of the lake basin, and 7,900 feet at the upper, or northern, end (Rinehart and Ross, 1957).



Map 2. Index map.

Because it was the windward shore, and also because it was close under the lee of McGee Mountain, lake features are not conspicuous around the mountain base. Perhaps the most striking is the 4,000-foot-wide, gravel-capped terrace which bevels the Sherwin glacial deposits that are draped over the basal slope of the northern flank of the mountain. The terrace gravels grade into the large, deeply dissected alluvial fan at the eastern end of Tobacco Flat which is made in large part of glaciofluviatile deposits of the Tahoe glacial stage.

The exceptional width of the terrace probably results from (1) its exposed position directly in the windstream that swept in the Pleistocene, as it does today, across what was then a shallow lake, but now is the mournfully desolate, gravel-floored plain stretching westward from the mouth of Convict Canyon; (2) the slight depth of water covering the terrace, which enabled waves to drag readily across the bottom; and (3) the ease with which waves scoured the glacial till.



Map 3. Location map

Elsewhere, the shorelines are inconspicuous. They are far more persistent on the basal Sierran slopes than at the mountain base itself or on the crescentic moraines that are looped around the entrance to McGee Canyon. The steep cliff marking the eastern end of the broad terrace, about a mile south of Whitmore Hot Springs, is a puzzling feature. Its origin may be due in part to displacement by recent faulting, and in part to wave erosion when the surface of Long Valley Lake stood at about 6,960 feet. Lake Crowley, named for Fr. J. J. Crowley, is a storage reservoir maintained by the Department of Water and Power of the City of Los Angeles, and is a diminutive remnant indeed of what must once have been a most impressive intermontane water body.

Long Valley almost certainly is a down-dropped, fault-bounded block. The

surface evidence for the recency of faulting is most striking, including conspicuous scarps that cut the more recent of the Tioga moraines as well as the modern alluvial fans. Geophysical data strongly corroborate the surface evidences of faulting. According to a gravity survey by Pakiser and Kane (1956), Long Valley is a fault-encircled trough filled in with 12,000 feet of material less dense than the immediately adjacent Sierran bedrock. This figure seems high, but it may be that more low density material, such as pumice, may underlie Long Valley than was allowed for in making the necessary corrections. There is no quarrel with the idea, as abundantly demonstrated by gravity measurements and geologic mapping of the circumferential faults, that Long Valley is a block downdropped relative to the Sierra Nevada, the Benton Range, and the Glass Mountain Range.

Coincidentally with its depression and with the elevation of the adjacent Sierra Nevada, Long Valley was filled with a thick prism of detritus, and very probably with volcanic material as well. What is needed, however, is a deep boring to determine the true nature and thickness of this fill.

At any rate, the visible floor of Long Valley consists of (1) floodplain deposits of the Owens River and its tributaries, and of McGee and Convict creeks; (2) lake deposits of Long Valley Lake; and (3) small alluvial fans built out into the valley from the bold escarpment of McGee Mountain.

SIERRA NEVADA

In spite of a century's study of this extraordinary range, its true nature is far from being understood. Not only are the characteristics of the original geosyncline and the mode of emplacement of the Sierran plutons subjects of debate, but the origin of its peculiar asymmetrical cross-profile is still a matter for conjecture.

McGee Mountain is perhaps unique in the central part of the eastern Sierra Nevada for its well-preserved capping of till, and to a lesser degree for the accompanying volcanic rocks; it is the presence of these two Late Cenozoic accumulations high up on the Sierran slopes that is the leading reason for the selection of this particular mountain as the site for a study.

Of more general relevance to the rest of the Sierra Nevada is the relationship of the internal conjugate fault pattern to the form of the range front. The geologic map (map 1, in pocket) shows very clearly that there is no single frontal fault at the base of the mountain. Rather, the mountain is broken by two major sets of rather closely spaced faults, one trending about N. 50° W., the other around N. 20° W. There is almost every reason to believe that a comparable array of closely spaced fractures extends out under the alluvium-blanketed floor of Long Valley.

In other words, the Sierra Nevada has been elevated and Long Valley depressed, not along a single enormous fracture, but as the result of additive movement along a whole system of fractures. This is not to say, however, that every fault has had an equal amount of displacement. Two fault zones appear to have been somewhat more active than the others, and these are (1) at the eastern base of Mt. Morrison, and (2) along the eastern and northern escarpments of McGee Mountain.

The result of the apparent concentration of greater displacement in these two

zones has been to elevate the range in two prodigious steps. The broad bench between Mt. Morrison and the range front is comparable to one of the treads of this cyclopean stairway, and is actually the upland surface upon which the McGee till rests. Although it too is cut by faults, the displacement along these has been relatively modest, and my opinion is that prior to the deposition of the McGee till the broad surface upon which the pre-McGee basalt rests, and which truncates the underlying steeply inclined metamorphic rocks, was cut in much the same manner as a pediment.

The presence of these broad benches has been long known. In fact, they were commented on by I. C. Russell (1889, p. 277) in a prescient observation based on a strikingly similar occurrence on the eastern face of Mt. Warren 30 miles northwest of McGee Mountain:

> There is one feature of the Sierra Nevada that presents itself when the mountains are viewed from the northern shore of Lake Mono which cannot fail to impress every geologist who visits the valley. . . . there is a terrace-like shoulder all along the eastern slope of Mt. Warren, which may also be seen to the north of Lundy Canon. This shoulder is in reality a broad terrace much modified by erosion. . . The mountain slope rising above it has much the appearance of a sea cliff long exposed to storms and frost. . . Its topographic form, especially when the mountains are white with snow, is accented by the dark forest of pine clothing it. Whether this peculiar feature occurs elsewhere along the eastern face of the Sierra Nevada or not, has not been ascertained; but it is so conspicuous at Lake Mono that when the structure of the range is studied it will demand attention.

A further point to be made at this time is the relationship of the faults to the range front, both in plan and profile. Considering the profile first, it is obvious from the cross section on the geologic map that the dip of the faults—about 70°—is far steeper than the slope of the mountain front, which averages 25°. This same discrepancy was pointed out in my paper (Putnam, 1960*a*, p. 226) describing the region at the mouth of Rock Creek, and has been alluded to by Gilluly (1928) for a similar relationship in the Oquirrh Range of Utah.

The inclination of the mountain slope is lower than that of the faults at its base, as well as that of those cutting it, making it abundantly clear that the mountain front is not a simple fault scarp. Rather, it is a deceivingly simple, yet, actually, most complex surface. In part, it is a graded slope for the kinds of rock cropping out there, as they are shaped by the processes that determine the prevailing erosional regimen: in part, it is a slope that has been disturbed by intermittent activity along the faults that intersect it.

In the environment of today, the frontal slope of McGee Mountain is under a quite different climatic regime than that of 11,500 years or so ago, in the declining phase of the last glaciation, and it is quite impossible for me to tell whether downwasting or parallel retreat is dominant. Perhaps the eastern Sierra Nevada is not a favorable locale in which to find an answer to this vexing question, but the true nature and probable future behavior of this 3,000-foot, essentially continuous slope would be an interesting problem to solve.

In plan, McGee Mountain occupies a crucial position with respect to the neighboring sectors of the Sierra Nevada. This part of the range, unlike the Mt. Whitney segment 70 miles to the south, does not have a simple linear front stretching unbrokenly for at least 40 miles. In the McGee sector the frontal scarp is as

abrupt as to the south, but instead of making a straight-line pattern on the map, it is part of a rectilinear one of sharp salients and deep reëntrants. McGee Mountain is such a salient with a reëntrant to the south of it toward Hilton Creek, and one to the west toward Mammoth Creek.

According to Gilbert (1941), this rectilinear pattern for the frontal faults is a fundamental one for the region, and may in large part be inherited from an ancient fracture pattern in the underlying bedrock. Renewed movement along these fractures was transmitted upward through the thin and patchy veneer of sedimentary and volcanic rocks. Certainly the rectilinear pattern of the range front with deep indentations and salients, such as at McGee Mountain, marking such abrupt changes in trend, makes this part of the Sierran escarpment contrast strongly with the configuration of the range south of Bishop.

Climate and Vegetation

That the climate of the McGee Mountain area is one of extremes is an expectable consequence of its position. In the first place, the east slope of the mountain and Long Valley at its base are in the rain shadow of the Sierra. The resulting drought is expressed in the landscape by the paucity of streams and by the ubiquitous mantle of sage and other semidesert shrubs. Second, the generally high altitude makes for strong temperature differences, both diurnal and seasonal.

The rainfall record from 1940 to 1953, as kept by the Los Angeles Department of Water and Power at its station at Long Valley Dam, at the downstream end of Lake Crowley probably is representative of the valley floor: January, 1.43; February, 1.74; March, 1.11; April, 0.56; May, 0.44; June, 0.33; July, 0.30; August, 0.28; September, 0.20; October, 0.45; November, 0.89; December, 1.81; total, 9.54 inches. These figures show not only how slight the precipitation is, but also that most of it takes place in winter.

Winter temperatures are low, cold enough that Lake Crowley freezes and higher slopes remain drifted over with snow. During summer, many days are uncomfortably hot, especially at altitudes below 8,000 feet, but nights are cool.

With the steep temperature gradient that exists locally, especially in a mountainous desert such as this, strong winds are common. The top of the mountain is windswept, and mountain-valley breezes are characteristic of the canyons of McGee and Convict creeks. Most vexatious of these winds is the nearly constant one that blows eastward, especially in summer afternoons, across the lugubrious wasteland of the sage- and gravel-covered plain north of the moraines enclosing Convict Lake. This is the wind that pours through Mammoth Pass, west of here at the head of the San Joaquin River, and results from the great difference in temperature between the two sides of the Sierra Nevada.

The vegetation pattern of the area reflects the harshness of the climate. The outstanding impression McGee Mountain gives is one of desolation. The slopes show little of the tidy, ladderlike progression of life zones illustrated in guidebooks or familiar to visitors to such frequented spots as the national or state parks in the Sierra Nevada.

Long Valley and the base of the Sierra Nevada are in the Upper Sonoran Life Zone, and the characteristic plants are basin sage and rabbit brush. In higher

parts of the zone Sierra juniper occurs together with a very few, hardy, isolated piñon. Willows flourish along the streams and irrigation ditches, and grasses, reeds, and water plants abound near the shore of Lake Crowley.

The sage community continues uninterruptedly up to the broad summit plateau of McGee Mountain. There, the individual plants are smaller and hug the ground tightly in order to survive in the face of what must be truly arctic rigors in the winter.

No parklike stands of Jeffrey pine grace the intermediate heights of the mountain, as they do at comparable altitudes along the eastern slope of the Sierra Nevada a few miles farther north. The only representatives of this stately tree in the vicinity of McGee Mountain are a few individuals scattered along Convict and McGee creeks and at the margins of Convict Lake. In all these sites they mingle with other elements of the gallery forest of alder, aspen, and willow. A widely dispersed stand of scrawny Jeffrey pine and piñon is deployed over the craggy surface of the rhyolitic rocks in the vicinity of Whitmore Hot Springs near the northern boundary of the area.

In the Hudsonian Life Zone, at the top of McGee Mountain, the sage and other shrubs are dwarfed, being seldom more than six inches high, and even less at altitudes above 10,400 feet. Broad expanses of the summit plateau are paved with frost-shattered rock, or with gravelly or sandy expanses of till. The most distinctive tree in this bleak alpine world is the white-bark pine. These low, flexible trees grow in stands that often are shaved off to a common height by the savage sweep of the high-altitude winds. They tend to cluster in rather open forests, chiefly on the sandy soil of the McGee till, and then dominantly on north-facing slopes.

ROCK UNITS

Paleozoic Contact-Metamorphic Rocks

As shown by the geologic map, about two-thirds of McGee Mountain is underlain by rocks that appear to have had a sedimentary origin and to have been dominantly fine-grained, such as shale, thin-bedded clayey sandstone, and calcareous quartz sandstone. They were metamorphosed into quartz-sericite hornfels, siliceous hornfels, and dark red or black phyllite. The limestone was converted to calc-hornfels, which exhibits a wide variety of forms. Some of these are calc-silicate rocks and others are marble. A number very likely were arenaceous limestones originally, and relic patterns such as cross-bedding are discernible today, especially where etched out by solution or by the keening winds that stream across the Sierran summit. Based on their fossil content (Rinehart, Ross, and Huber, 1959), these rocks are Ordovician.

Tactite bodies of small extent are marginal to the contact with the granitic rocks underlying the northern slope of McGee Mountain. The most conspicuous one is at the extreme edge of the summit upland where it falls away from the escarpment of McGee Mountain. This particular outcrop has been opened for the so-called Tiptop Prospect, and the jeep trail built to it provides the only vehicular access to the top of the mountain. The rock is dense, extremely heavy, and makes a dark-brown, reddish-brown, or black outcrop. Visible in the rock are

reddish-brown garnet, dark pyroxene and amphibole, epidote, calcite, and quartz.

The calcareous rocks, very likely as a consequence of the aridity of this trans-Sierran region, are among the more resistant to weathering. They form prominent ridges and pinnacles of grayish, gnarled, and knotted-looking rocks, much bolder and more barren looking than those of the neighboring granitic rocks.

The aluminous hornfels breaks up readily under the active mechanical weathering prevalent in this alpine world and disintegrates to form angular, slatelike, tabular fragments, rarely more than 2 or 3 inches across. They make a nearly unbroken pavement of frost-sundered rocks on broad and gentle slopes, or long screes of red and black fragments mantling steeper declivities.

Mesozoic Intrusive Rocks

QUARTZ MONZONITE

Intrusive igneous rocks crop out along the northeasterly slope of McGee Mountain in a relatively continuous body having an area of approximately four square miles. In the field, this rock appears to be a quartz monzonite with about the same mineralogic composition as assigned by Rinehart and Ross (1957) and Bateman (1961) to the nearby quartz monzonite of Wheeler Crest, namely, 20–45 per cent potash feldspar, 20–45 per cent plagioclase feldspar, 20–50 per cent quartz, 1–10 per cent biotite, and a trace of hornblende. Characteristically, it is light to medium gray; dark phases are rare. The texture is medium-grained, although locally coarse-grained varieties do occur, and some are porphyritic, with feldspar crystals up to an inch or so in length.

The age of this body of granitic rock probably is Cretaceous if it is related to the much larger plutons of similar rock in the immediately adjacent Sierra Nevada (Rinehart and Ross, 1957) and the neighboring Yosemite Valley region (Curtis, Evernden, and Lipson, 1958).

The contact of the quartz monozonite with the hornfels is intrusive. The relation is very clear where the contact has been laid bare in the open pit of the Tiptop Prospect. Small dikes penetrate deeply along favorable layers in the hornfels and shun less receptive ones, thus producing an irregular jigsaw boundary between the two. The contact zone, however, has proved to be a region of relatively high susceptibility to mechanical failure when subjected to stress, and, as shown on the geologic map, it is followed closely by faults for nearly all its exposed length.

The monzonite itself is strongly sheared, and is broken by a multitude of joints, although they are by no means as closely spaced as in the aluminous hornfels. The result is that the intrusive rocks do not make conspicuous outcrops, except locally, as near the mouth of McGee Canyon where a number of bold spires and ridges add diversity to the McGee escarpment.

Tertiary (?) Volcanic Rocks

basalt

The geologic map shows the discontinuous distribution of a small basalt flow on the McGee Mountain summit upland. The reasons for the noncontinuity of outcrop are threefold: (1) the basalt has been displaced by faults, (2) about one-third of it is overlain by the younger McGee till, and (3) part of it has been moved downslope by landsliding.

The basalt is dark gray on fresh surfaces. Most of the denser phases of the basalt weather to shades of brown or deep reddish-brown. Scoriaceous portions weather to a very conspicuous bright red, and these reddish areas stand out in striking contrast to the nearly white, or very light-gray, boulders of the overlying McGee till.

Vesicular and scoriaceous varieties of basalt are the most abundantly visible kinds, since what must have been close to the original pre-McGee surface of the flow is widely exposed on the top of the mountain. A cliff section cutting through the flow is at the extreme northern face of McGee Mountain, and there the dense, iron-gray groundmass can be seen to contain phenocrysts of augite and olivine. The flow appears to have a maximum thickness of about 100 feet. As pointed out by Gilbert (1941, p. 794): "Indeed a small basalt exposure on McGee Mountain lies in an old valley, later the path of an early glacier which left its moraine on the basalt (McGee stage of Blackwelder, 1931, pp. 902–906)."

The geometric relationship of this basalt to the Sierran escarpment is of crucial importance in deciphering the tectonic history of the range. The age of the basalt is of equal significance, too, because this is locally the oldest of the superjacent, nearly horizontal volcanic and sedimentary rocks of Cenozoic age resting on the metamorphic and intrusive terrane of the Sierra Nevada.

The cross section accompanying the geologic map shows that the basalt terminates abruptly at the escarpment bordering the summit upland of McGee Mountain. This is at an altitude of 9,840 feet, and a downfaulted possible equivalent exposed in the walls of the Owens Gorge, although of widely variable thickness and much broken by faults, stands at an average altitude of about 6,500 feet. Allowing a reasonable northward inclination of the bedrock surface upon which the basalt rests, this gives a probable total displacement of 9,000 feet in the vicinity of McGee Mountain.

The question of the age of the basalt is a vital one. There is nothing in the McGee Mountain area to disprove a Pleistocene age for the basalt, and I am strongly inclined to the belief that it is Pleistocene rather than Pliocene. Gilbert (1941, pp. 800–804) believed that it was Pliocene on the basis of correlating the basalts, which are widespread south of Mono Lake, with a similar volcanic sequence overlying the Esmeralda formation near Hawthorne in western Nevada.

A more precise determination of the age of a nearby basalt is made possible through the investigation of a pollen florule recovered from a layer of tuffaceous sandstone and shale only 3 or 4 inches to 3.5 feet thick underlying the basalt in the Owens Gorge, 13 miles east of here. Axelrod and Ting (1960, pp. 10–13) correlate this pollen-bearing, thin clastic wedge under the basalt with the Coso

formation, about a hundred miles to the south, which contains a Late Pliocene mammalian fauna, as well as a pollen flora correlative with that of the Owens Gorge.

I deeply regret that I did not appreciate the significance of this subbasaltic sedimentary material at the time the Owens Gorge Tunnel was being driven. My recollection is that several feet were exposed directly under the basalt, and that the lowermost part of the material was a paleosol overlying the weathered granite bedrock. Basaltic cinders, as I recall, were also part of the unit, and since these were directly beneath the basalt itself, they probably heralded the advancing flow.

The evidence of the Owens Gorge spore-pollen florule from immediately below the basalt indicates that the region then supported a humid Yellow-pine forest (it is a piñon woodland today), much like that of the contemporary middle altitude western slope of the Sierra Nevada. The annual precipitation then probably averaged around 35 inches, with a fair amount of it in the summer, as contrasted to the paucity of summer rain today, and the annual average of only about 10 inches.

Quaternary Volcanic and Sedimentary Rocks

McGee Till

Overlying the Late Pliocene (?) basalt on the summit upland of McGee Mountain is the McGee till. This name was first given to the deposit by Blackwelder (1930) in an abstract, and described in more detail in a later paper. It was also investigated at about the same time by E. B. Mayo (1934*b*), then a student of Blackwelder's at Stanford University.

The McGee till, as shown on the geologic map, occurs as five separated ridge-capping bodies. The largest has a length of nearly 2 miles and an average width of 0.5 mile. It caps the ridge overlooking Convict Lake, and makes a nearly continuous blanket with a maximum thickness, as taken from the map, of approximately 600 feet; because of mass movement, 500 feet might be closer to the true thickness. This is the body of till that is visible from U. S. Highway 395 north of the mountain as an ash-gray blanket dotted with white boulders—much resembling a distant band of sheep—standing out in strong contrast to the somber reds and browns of the underlying metamorphic rocks. All told, the McGee till ranges vertically through slightly more than a thousand feet, from an altitude of 10,800 feet near the base of Mt. Morrison down to 9,720 feet at the eastern brink of the upland surface.

As pointed out by Blackwelder (1931, pp. 902–903), the majority of the rock fragments in the till are granitic. This is certainly true of the larger ones, and some are quite large indeed. The largest erratic measured by him was a block whose dimensions above ground gave a volume of 4,032 cubic feet. The finer matrix of the till does contain a large percentage of hornfels fragments; the amount of hornfels increases to dominance toward Mt. Morrison, but decreases eastward toward Long Valley so that the eastern patches of till consist very largely of granitic debris.

The great amount of granitic detritus in the McGee till is one of the leading arguments advanced by Blackwelder (1931) to demonstrate that the accumulation has

a glacial origin, rather than being a mudflow or a landslide. The possibility of a landslide is remote indeed, because, then, as now, the mountain slopes standing above the McGee upland bench, such as Mt. Morrison and its neighbors, were underlain by hornfels. The nearest outcrop of granitic rocks, and the most likely source for the boulders in the till, is the outcrop of quartz monzonite approximately 3 miles south in McGee Canyon. Had these boulders been transported to the present site of the McGee till across the topography of today, it would have been necessary for the glacier to climb a canyon wall 2,000 feet high in order to place them on the ridge crest where they now repose. This clearly shows that the McGee till was deposited before the canyon of McGee Creek was excavated.

Whether the McGee till had a glacial origin, or whether it was a mudflow deposit is difficult to answer. After looking at both sorts of deposit for many years, no unequivocal criteria are known to me which can be used to distinguish one from the other, especially as they may stand revealed in road cuts, gravel pits, and similar excavations.

The decision here must be made on the basis of the importance to be attached to the location in terms of its environment, and the relative probability that it is one sort of deposit rather than the other. For me, Blackwelder (1931, pp. 902–904) summarizes the situation cogently:

> Since the material consists largely of granitic rock and yet rests upon metamorphic sedimentaries it must be a transported deposit. Hence its boulders cannot be due to exfoliation and decay in place. It is estimated that 10 to 30 per cent of the material consists of boulders. Many of the blocks exceed 10 feet, some 15, and a few even 20 feet in length. The dimensions of the largest are 28 by 16 by 9 feet. Transported material of these characteristics seems possible only in the deposits of mudflows, landslides, or glaciers. To differentiate these three, under the circumstances of this case is difficult because most of the essential criteria are lacking. Topographic forms and physiographic relations have been wholly destroyed by erosion. There are no large excavations available, and a search of the deposit during two visits to the mountain did not yield any boulders that show definite glacial scratches, although a few showed vague forms and grooves that are suggestive of glacial action. A single striated cobble of quartz slate was later found by Mr. Matthes in the course of a visit to the crest of Mt. McGee. The scarcity of striated stones may be explained by several considerations. About 95 per cent of the boulders consist of granite and a little marble—rocks that are so susceptible to decay that none of them show any trace of their original surfaces. Most of them are deeply cavernous and crumbling. The remaining quartzite, hornfels, and slate fragments should retain any markings they may have had, but it is significant that, on descending over the moraine of the Tahoe stage, where such dense rocks form more than two-thirds of the boulders, the writer found only six striated fragments, all of which were rather obscure. It is common observation that glaciated stones are much less plentiful on alpine moraines than on ice-sheet till. For these reasons the scarcity of striated stones in the McGee tilloid need not be given undue weight.
>
> It is perhaps significant that the McGee deposits can be proved to have been transported as much as 3½ miles from the parent outcrops. This is rather a long distance for landslides, but not for mudflows and glaciers. Their position close to the main divide of the Sierra Nevada, where glaciers have reigned in successive epochs, reinforces the writer's inference that they too are of glacial origin, but the opinion is not established beyond reasonable doubt.

I might add that I have found several faceted and striated blocks in the McGee till of the summit upland, one of which is illustrated (pl. 1, *a*). It is true they are uncommon, but this in part is due to their relative rarity in even the most recent Sierran moraines. It is also due in part to the severe weathering that exposed

boulders of McGee till have undergone. Only the most protected ones, and they are few, show characteristic glacial features.

The deep weathering of the quartz monzonite boulders in the McGee till has been noted by every observer. Many of the boulders that are exposed to the full fury of high Sierran wind and snow storms are sculptured into bizarre shapes (pl. 3, *b*). The most striking feature is that the dark, finer-grained inclusions in these granitic rocks have proved more resistant than the coarser-grained matrix of the rock, which consists dominantly of quartz and feldspar crystals. The result of this differential weathering is that the inclusions stand out as knobs, many of them projecting as much as 4 to 5 inches above the smoothed and blasted parent rock.

Solution pits, reminiscent of Indian corn-grinding basins, or of small pot holes, are common indeed where boulder surfaces are reasonably level and sheltered.

If the glacial origin of this bouldery deposit perched far up on an isolated shoulder of the Sierra Nevada is accepted, then the next problems to be resolved are: (1) its relationship to the tectonic and erosional history of the range, and (2) its correlation with other glacial deposits here in the Sierra Nevada and elsewhere in North America.

With respect to the first problem: Since the McGee till was deposited, the range of which it is a part has been uplifted a minimum of 3,500 feet—presumably largely by faulting, but with warping playing an indeterminate but possibly significant role. This is a minimum figure because the downfaulted extension of the McGee till and its associated glaciofluviatile deposits, beyond where they are truncated by the Sierran escarpment, are concealed by the alluvium of Long Valley. Assuming a depth of burial of around 500 feet, this would make the post-McGee uplift of this segment of the Sierra Nevada amount to approximately 4,000 feet. Concurrently with this uplift the two canyons of McGee and Convict creeks were eroded to depths of 2,000 to 3,000 feet below the McGee summit upland.

Interestingly enough there are other bouldery accumulations throughout the Sierra Nevada bearing a similar inharmonious relationship to their surroundings; i.e., perched on ridges and isolated summits flanked by deep canyons incised in such resistant materials as granitic and metamorphic rocks. Among these is a wide till-covered bench on the eastern slope of the Sierra Nevada between Bishop and Big Pine (Knopf and Kirk, 1918, pp. 93–94). This extensive body is unusual because here glacial till grades into glaciofluviatile deposits, thus clearly establishing its mode of origin (Axelrod, personal communication). Other bouldery accumulations are at Minaret Pass (the divide separating the drainage basins of Mammoth Creek and the San Joaquin River), Ebbetts Pass, and the mountainous area around the forks of the West Walker River, northwest of Bridgeport (Blackwelder, 1931, pp. 904–906). Less well known are such deposits on the western slope of the range, although they have been described for the Yosemite Valley area by Matthes (1930, pp. 62–65).

The age of the McGee till is very nearly as much a matter of uncertainty today as it was thirty years ago when it was first described. Blackwelder (1931, p. 918) considered the McGee to be the equivalent in time of the Nebraskan glacial stage of the central United States. He was disturbed in this attempt at establishing a correlation with the standard section of the Mississippi Valley by the seeming

absence in the Sierra Nevada of a stage that was a time-equivalent of the Illinoian.

My opinion (1960*b*) is that the McGee is more likely to be contemporaneous with the Kansan. This belief is based on the evidence advanced by Axelrod and Ting (1961, pp. 139–141) that the Sierra Nevada did not stand sufficiently high in the Early Pleistocene for extensive glaciation to have occurred along its crest. In other words, it is a time-equivalent of the Nebraskan stage that is missing in the central Sierra Nevada, rather than a contemporary of the Illinoian.

SHERWIN TILL

The next younger of the glacial deposits marginal to McGee Mountain is the Sherwin till. The type locality for this glacial stage, named by Blackwelder (1931, p. 895), is about 11 miles south on Sherwin Hill, a short distance from Bishop. The fundamental difference between the McGee and the Sherwin tills is that the latter is related to the present-day canyons, while the former, stranded high on a mountain upland, is not.

The Sherwin till at its type locality, and elsewhere throughout the Sierra Nevada, has more deeply weathered boulders and matrix than do its successors, the Tioga and Tahoe tills. Furthermore, constructional forms, such as individual morainal ridges, are customarily lacking, and deposits of Sherwin till commonly have a more blurred appearance. That is, moraines are recognizable but they lack the sharp configuration, for example, of Tioga moraines.

The Sherwin at the type locality near the south end of Long Valley is readily separable from later glacial deposits, because interposed between it and them is the Bishop tuff. That this ignimbrite and pumice rests on the surface of the Sherwin till can be seen clearly in the walls of the Owens Gorge, and was also demonstrated conclusively in a tunnel driven by the Department of Water and Power of the City of Los Angeles in the years 1949–1951 (Putnam, 1960*a*). Unfortunately, the relations are not so clear cut at McGee Mountain, because the Bishop tuff does not extend into the terrain that I interpret as being underlain by Sherwin till.

The great morainal ridge which stands approximately 1,000 feet high at the northern base of McGee Mountain is shown on the geologic map as Sherwin till. The reasons for this decision are largely subjective. They are based in part on the affinities of this moraine to its neighbors, which are similar here to those in other glaciated canyon mouths where Sherwin till unquestionably is present. The Sherwin moraine here, as elsewhere, is bulkier and extends farther out from the mountain front than do the moraines of its successors. The Sherwin tills commonly are more deeply weathered than those of the Tahoe and Tioga stages, and this appears to be true here, as well. This, however, is a criterion that must, it seems to me, be applied with great caution. Much depends on whether identical, or nearly identical, rock types are being compared in any determination of relative weathering. Equally important, too, are the environmental factors that are operating. The rate and kind of weathering of morainal debris is likely to be markedly unlike in the Sonoran, Transition, and Alpine Life zones. Another criterion of some validity is the amount of displacement on the faults cutting the various moraines. All are

faulted, and in general the amount of displacement decreases with recency of age; older moraines are offset more than younger.

Keeping all these factors in mind, my opinion is that the enormous, sage-covered, somber gray moraine that partly blocks the entrance to Convict Canyon is of the Sherwin glacial stage, rather than the Tahoe. It has been scoured on its upstream face by the later advance of the Tahoe glacier, and the mountain-facing side of the Sherwin moraine is plastered with Tahoe till.

I am much less certain about the age of the large lobate moraine sealing the entrance to McGee Canyon. It, too, is a massive deposit, with a height of 800 feet and a length of 1.5 miles. The demarcation between what appears to be unquestioned Tahoe moraine and what may be Sherwin beyond is unclear here, at least to me. The entire moraine is shown on the geologic map as Tahoe. The provisional contact indicated by a dashed line within the area of Tahoe till may well be the boundary between the two glacial stages, but after considering all the evidence available, I prefer to believe that the contact marks the dividing line between two subdivisions of the Tahoe, rather than between two such widely separated stages as the Tahoe and the Sherwin. If Sherwin till is present here, it well may be the foundation upon which the Tahoe moraine is built, and this may in part explain the enormous bulk of this glacial deposit.

RHYOLITE

The geologic map shows an area of approximately one square mile of rhyolitic rocks north of U.S. Highway 395 and immediately adjacent to Whitmore Hot Springs. These volcanic rocks are chiefly pumice and obsidian. The latter includes the familiar jet-black, conchoidally fractured variety, as well as cliff-making layers of a gray, stony, pumiceous type with pronounced flow banding. The two are gradational.

These rhyolitic rocks stand out in craggy desolation, much as though they were part of an immense ruined wall dominating the sage plain at the base. A half-mile-wide corridor which separates these rhyolitic cliffs on the north from the Sherwin morainal ridge on the south provides a route for U. S. Highway 395, as well as for the channel of Convict Creek. This same corridor is paved with boulders, gravel, and sand; in part these are stream deposits, in part they are glacial outwash, and in part they are lacustrine.

The broad swath of alluvium effectively conceals the contact between the rhyolitic rocks and the Sherwin till. As a result I cannot tell definitely which of these units overlies the other, but I believe it more likely that the rhyolitic rocks are younger than the Sherwin till. This means, in my interpretation, that the rhyolite and pumice are essentially time-equivalent to the Bishop tuff, whose nearest outcrop is 3 miles east of McGee Mountain. My opinion is that the obsidian and pumice are precursors of the eruption of the *nuees ardentes* responsible for the broad distribution of the Bishop tuff over 400 square miles of the country east of the Sierra Nevada.

Rinehart and Ross (1957) appear to be equally troubled about the age of these cliff-making obsidian flows and intercalated pumice layers. They assign them a Tertiary age in the Glass Mountain area, on the east side of Long Valley, and on

their geologic map show them as directly below the Bishop tuff. They also indicate the alternative possibility that these obsidian flows and pumice are closely related in time to the Bishop tuff. Their geologic-map description follows (Tr is Tertiary rhyolite; Qb is Quaternary Bishop tuff).

RHYOLITE: Perlitic glass and obsidian in northeast part of quadrangle; east of Long Valley includes somewhat alluviated pumice-covered areas with resistant glass knobs and hummocky terrain covered with glass rubble. The pumice may be in part, unconsolidated Qb, especially near Qb outcrops; a considerable amount of glass is commonly associated with Tr and serves to distinguish it from unconsolidated Qb, which typically is glass free.

I believe that the presence or absence of glass fragments is more likely to be one of the vagaries of a series of explosive eruptions than it is to be a time indicator sufficiently diagnostic to place the obsidian flows in the Tertiary. This would separate them from the Bishop tuff by the eruption of basalt, the deposition of the McGee and Tahoe tills, as well as by the 3,000 feet or so of displacement along the Sierran frontal faults before the Sherwin glacial stage.

Should these pumice layers and obsidian flows prove to be time-equivalents of the Bishop tuff, then they presumably have an isotopic age of about a million years, based on potassium-argon dates as determined by Evernden and Curtis (1962). Finally, these obsidian flows near Whitmore Hot Springs appear to be much more a part of the present landscape than they would were they older than the McGee glacial stage, which inevitably would be the case were they of Tertiary age.

In other words, although the evidence is not conclusive, the most reasonable interpretation seems to be that the pumice and obsidian flows were erupted following the blocking out of the Sierran escarpment, that they are closely related in time to the emplacement of the Bishop tuff, and that they are post-Sherwin in age.

TAHOE TILL

The Tahoe glacial stage was named by Blackwelder (1931, p. 884) on a regional basis, rather than for a specific type locality as is true for the Sherwin and McGee stages.

As Blackwelder points out, the Tahoe moraines are characteristically the most impressive ones at the mouths of existing Sierra canyons. This is as true for the entire segment of the range with which I am familiar, extending from Bishop on the south to Mono Lake on the north, as it is for the mouths of Convict and McGee canyons.

The principal difference between Tahoe and Sherwin moraines, as mentioned earlier, is that, although the Sherwin moraines are much more widespread than the Tahoe stage moraines, they lack the sharp definition of the latter. Although this statement is true in general, it applies with greater force to the later phases of Tahoe glaciation than to the earlier. The early Tahoe moraines sometimes are difficult to separate from Sherwin morainal deposits, and this is especially true at McGee Creek.

Birman (1957) made an intensive and detailed study of the glacial deposits in the upper drainage of the San Joaquin River, almost directly across the Sierran crest from here, and he concluded that the Tahoe glacial stage was divisible into

two parts, to which he gave the names of Tahoe (older) and Graveyard (younger).

The pattern of Tahoe moraines near Convict Lake lends strong support to this conclusion. The geologic map shows that one arm of the Tahoe ice moved down the axis of what is now Tobacco Flat, while the other followed the course of modern Convict Creek, and then spread out in a broad, lobate front beyond the base of the Sierra Nevada.

The two arms, formed as the ice divided around the buttress of the Sherwin morainal ridge, were not contemporaries. The Tobacco Flat arm is older since it is crosscut by Tahoe (Graveyard), and also by Tioga moraines. Further, the Tobacco Flat trough appears to have been graded to the level of the broad terrace that marks the high stand of Long Valley Lake, while the Convict Lake lobe apparently was graded to a level 100 to 200 feet or so lower. The floor of the present-day Convict Creek glacial trough is about 300 feet lower than the Tobacco Flat trough, no doubt because of additional excavation by later Tahoe and Tioga ice.

This bifurcation near the terminus of the Convict Creek glacier was described by Kesseli (1941), and is interpreted by him as resulting from an advance, a withdrawal, and then a later advance following a new course, developed perhaps as a result of the breaching of the lateral moraine by a stream during the interval when the trough was vacated by the ice. The interglacial stream valley that was cut through the moraine provided a route for the readvancing ice to follow.

A twofold advance of ice, the second on a front slightly different from that of the first, is also indicated by the morainal pattern at the mouth of McGee Canyon. This, too, was remarked upon by Kesseli (1941), and, indeed, if the outer moraines of this complex system actually are all of Tahoe age, this sequence of an advance, a withdrawal, and a later advance is evidence for the twofold division recognized by Birman (1957).

The absence of Sherwin till at the surface of the McGee Creek moraines is comparable to the situation in the morainal complexes at June and Grant lakes (Putnam, 1949), approximately 25 miles northwest. The Sherwin till there is buried beneath the later accumulations of the Tahoe and Tioga glacial stages. Quite the opposite situation prevails at the mouth of Rock Creek Canyon, where the Sherwin till is by far the areally dominant rock unit on the surface.

TIOGA TILL

The Tioga glacial stage was also established by Blackwelder (1931, pp. 881–884). It is based on the very recent-appearing glacial moraines on either side of the Tioga Pass on the eastern boundary of Yosemite National Park, 35 miles to the northwest.

In the eastern Sierra Nevada, moraines of the Tioga glaciation commonly are nested inside the bulkier moraines of the preceding Tahoe stage. Another criterion generally employed in distinguishing between the Tahoe and Tioga stages is that in most areas only Tioga terminal moraines have survived. Tahoe terminal moraines are lacking almost everywhere, most of them having been removed by meltwater streams from the Tioga glaciers. In brief, the combination of fresher boulders, sharper morainal ridges, smaller dimensions of lateral moraines, presence of terminal moraines, and their position nested inside the bulkier moraines of the Tahoe stage, all serve to distinguish glacial deposits of the Tioga stage.

That the Tioga is a true glacial stage, and not simply a recessional phase of the Tahoe, is demonstrated 25 miles north of here at June Lake. There, a small basaltic cinder cone and its accompanying flow were erupted in the trough vacated by the Tahoe ice, and were then partly glaciated by the advance of the Tioga glacier (Putnam, 1949).

OLDER ALLUVIUM, STREAM TERRACES, INACTIVE FANS, AND CONES

Included in this category on the geologic map are the deposits of inactive and now dissected fans, terraces, and nonglacial deposits, presumably of the Late Pleistocene. Many of these fans and screes were contemporary with the Tioga, and very possibly with the Tahoe glaciations.

Also included in the same map unit with these older fans and terrace deposits are the lacustrine gravels and other deposits of Long Valley Lake, including the broad terraces north and south of the flood plain of Convict Creek. On the terrace, approximately one-half mile south of Whitmore Hot Springs, these lake gravels merge with those of a wide alluvial fan constructed by the meltwater of the Tobacco Flat arm of the Convict Creek glacier.

Other lake deposits are on the floor of Long Valley, and these include clay, silt, sand, marl, and gravel. Some feebly cemented sandstone and tufa layers are in the vicinity of the Whitmore Hot Springs. The lake deposits are not differentiated from the older alluvian on the geologic map. Many of these lacustrine deposits almost certainly are contemporaneous with the Tahoe glacial stage, the time when Mayo (1934*a*) believes Long Valley Lake attained its maximum size.

ALLUVIUM

Deposits that are essentially related to the postglacial erosional cycle are shown separately from the older alluvium. For the most part, fans constructed in the latest Pleistocene are now being dissected, and the same is true of many of the lake and stream terraces. The cause of this dissection is unknown, but it may be related in large part to the climatic changes instituted 10,000 or 11,000 years ago with the ending of the Pleistocene glaciation.

The younger alluvium, then, includes the more recent fans, talus cones, and stream and lake sediments laid down since this episode of downcutting was initiated.

STRUCTURE

Pre-Tertiary Structures

The metamorphic rocks that make up most of the mass of McGee Mountain appear to have steep dips. Although some units, such as the calcareous rocks, stand out in bold relief and can be identified clearly both on the ground and on aerial photographs, they cannot be followed along the strike for long distances. The structure under the summit of the mountain is further obscured by the tattered blanket of basalt, McGee till, and frost-riven rocks that is spread loosely across the truncated edges of the upturned, recrystallized sedimentary rocks.

Gilbert's (1941, p. 783) succinct statement for the whole region southeast of Mono Lake is entirely applicable to the limited area of McGee Mountain:

The oldest rocks exposed in this area are all metamorphosed sediments—marble, mica schists, quartzite, and calc-silicate hornfels being the most common. These are intruded by granitic rocks so widely exposed by erosion that the metasediments are numerous small patches of obscure structure. Universal steep dips prove that they have been intensely folded.

Rinehart, Ross, and Huber (1959), in a paper concerned chiefly with the age and stratigraphy of these rocks, point out that they are steeply dipping. In general, they have their tops to the west, and in the vicinity of Mt. Morrison are essentially homoclinal.

The granitic rocks underlying the northeast flank of the mountain are intrusive into the hornfels, as can be seen clearly where the contact has been excavated in prospect pits. There, dikes and stringers of granitic material penetrate for considerable distances along favored layers. The granite-hornfels contact dips steeply, and although not wholly conformable, it does tend to follow the prevailing strike of the host rocks. The contact also appears to have been predisposed to failure under stress, since it is followed for most of its length by basin and range faults.

Basin and Range Faults

Most significant of the structures within McGee Mountain from the point of view of this study are the high-angle faults that cut all the rocks, including the youngest, and to a large extent are responsible for the elevation of the mountain to its present height.

On the geologic map it is immediately apparent that there are two major fault systems. One of these trends about N. 50° W.; the other, about N. 20° W. The first system virtually coincides with the trend of the range front from McGee Creek southeastward to the ridge bordering Rock Creek. The second system parallels the desert-facing escarpment of the Sierra Nevada from McGee Mountain westward, roughly following the same trend as the course of Mammoth Creek. Thus, the internal fault pattern of McGee Mountain is clearly related to the strategic position the mountain occupies as the salient where the range front makes a 60°–70° change in trend.

The faults appear to be high angle, with dips of approximately 70° or more. The evidence consists chiefly of their nearly straight-line pattern across terrain of high relief, the actual visible attitude of fault planes in cliff sections or where exposed on steep slopes, and the lack of offset where faults intersect.

What is the evidence that the faults shown on the map actually exist? The answer is that no single criterion was employed, but the pattern as shown on the map was built up by using a number of them. Movement on some of the faults was recent enough that scarps cross the Tioga moraines and Recent alluvial fans, or the faults themselves are visible as low cliffs cutting the bedrock at the base of the Sierra Nevada. Most impressive of these is the fault scarp slicing across the morainal festoon at the mouth of McGee Canyon, which has a height of 30 or 40 feet.

Other faults can be distinguished through more orthodox field methods on extremely steep slopes, or cliffs, or in canyons where unlike rocks have been brought into contact, where shattered zones are visible, or where the courses of subsequent streams can be identified.

The final criterion used for distinguishing these faults is perhaps the most controversial, just as it is assuredly the most subjective. This is their identification on aerial photographs. Fortunately, there is only the most sparse vegetation on the mountain, very little or no soil cover, and differences in ground color are very clear. Furthermore, linear elements, almost certainly related to a fracture pattern in the bedrock, show up with great clarity in some parts of the area and on some photographs. How many of these linear elements are to be interpreted as faults, and how many are not, is almost certain to be decided very largely by the photo interpreter's prejudices. I tried to make as conservative a selection as I could; to identify what appeared to be *bona fide* faults, not every crack in the ground. Wherever I felt reasonably confident of the evidence, I have tried to indicate on the map my opinion of what the relative movement may have been. In general, but by no means universally, the faults are down-thrown from the Sierra toward Long Valley.

How ancient are the faults? Other workers in the area consider them to be quite long-lived, and to be inherited from an earlier framework. According to Gilbert (1941, pp. 807–809):

Throughout the whole region faults strike in nearly every direction, though commonly between northeast and northwest. These nearly straight faults intersect and cross in angular fashion making a fault mosaic. Intersecting faults are not noticeably offset by one another, implying a negligible strike-slip component and a slip commonly down the intersection of the two faults. Such faults probably formed contemporaneously.

Though the individual faults are nearly straight lines, the lines of major displacement, shown by the fault scarps, bend in an angular or zigzag fashion. Such scarps are defined by more than one fault, the major displacement following first one and then another of different strike. Where an angular re-entrant occurs in a scarp or both of the faults defining the re-entrant may continue with diminished displacement into the range. . . .

Thus, although the Benton Range, like many other ranges in the Great Basin, trends north-south for some 20 miles, few of the faults along which it was relatively uplifted have that trend. The White Mountains trend north-south, yet the fault scarps along it are not straight because they are defined by faults some of which strike at distinct angles to the north-south trend. The same is true of the Sierra Nevada and the Walker Range to the north near Hawthorne. Clearly the stress condition which existed throughout this region at the time of faulting was relieved by normal displacements along zones trending, like the ranges produced, between north and north-northwest. The many faults not following this trend suggest some pre-existing structural element which controlled the trend of individual surface faults. Presumably the stress control of the north-south zones of major displacement lay at depth while the element which governed the observed individual faults existed near the surface. To what depth this surface control may have extended cannot be determined.

Hulin (1931, p. 307) has suggested the term "subsequent faults" for displacements controlled by "previously existing planes of weakness." He took the Benton Range for the type region of "subsequent faulting" and suggested that the controlling planes of weakness might be defined by "joint planes, joint systems, or previously existing fissure systems." Both Mayo (1937, p. 182–183) and Chelikowsky (1940, p. 430–431) picture a similar control system by joint systems along the Sierra Nevada fault scarp near Long Valley and control of these joints by still earlier structures.

Spurr (1905, p. 79) suggested that zigzag fault scarps might be controlled by previously existing fractures, although he also suggested, without necessarily implying control by earlier structures, that they could be formed as lines of "equal dislocation" produced by intersection of two fault systems.

Rinehart and Ross (1957) seem also to share the opinion that the fault pattern is a long-enduring one, and one characterized by recurrent movement. They say:

> No faults of large offset were observed along the front of the Sierra Nevada. Many of the faults mapped along the front, however, cut and displace recent talus and alluvium, indicating that faulting is still active in this region. The position of these faults strongly suggests that at least some of them may reflect continued or recurrent movement along older faults, although the small part of the range included in the quadrangle precludes further discussion of the structural history of the Sierra Nevada.

They also point out, and my belief coincides with theirs (Putnam, 1960*a*, pp. 244–245), that warping has played a considerable role in the elevation of the range. How much actually to assign to warping, and how much to faulting, is indeterminate here because of the lack of such a convenient datum as the Bishop tuff provides elsewhere—for example, in the Owens Valley in the neighborhood of Bishop (Bateman, 1958).

A compensation for the lack of a means of making a clear-cut choice as to the relative weight to assign warping and faulting in raising McGee Mountain to its present lofty stance above the alluviated plain of Long Valley is the remarkable preservation of the McGee till on the mountain shoulder. This nearly level accumulation of till, and the underlying basalt, provide a datum for calculating the actual amount of uplift of the Sierra Nevada relative to the floor of Long Valley.

An absolute minimum value for the post-McGee movement of the Sierran frontal faults is 3,500 feet. Adding to this an estimated depth to which the downfaulted continuation of the basalt and McGee till are concealed beneath the alluvium of Long Valley, a conservative minimum value for the total amount of uplift for this segment of the range since the McGee glacial stage would be about 4,000 feet.

LATE CENOZOIC HISTORY OF THE EAST-CENTRAL SIERRA NEVADA

For more than a half-century the glacial story of the Sierra Nevada has excited the curiosity of investigators. In fact, the beginnings of the inquiry go back to the pioneering efforts of J. D. Whitney, Joseph Le Conte, and John Muir in the Civil War and Reconstruction eras. Of more direct relevance, however, are the studies of A. C. Lawson, F. E. Matthes, Eliot Blackwelder, A. Knopf, and H. W. Turner. They recognized not only the existence of more than one glacial stage, but that the mountains preserved a hierarchy of upland slopes and of valleys incised into one another that presumably recorded stages in the erosional history and uplift of the range.

According to Lawson (1904) and Matthes (1950), the system of valleys and upland surfaces adjacent to the Kern River, 70 miles south of McGee Mountain, might be represented as shown on the accompanying diagrammatic profile (fig. 1), which is similar to one developed by Axelrod (1962).

Lawson (1904) believed that the Subsummit Plateau dated from the Cretaceous and the High Valley Stage (Chagoopa) from the Early Quaternary. As Axelrod and Ting (1960, p. 37) point out, Matthes extended his erosional history far back into the Tertiary (he believed the Broad Valley Stage—Chagoopa Plateau—to be

Miocene) because of a misconception of the relationship of the Sierran erosion surfaces to the Cenozoic volcanic rocks of the Sierra Nevada.

The upland surface beveling the metamorphic rocks of McGee Mountain, and upon which the basalt and McGee till rest, in my opinion is equivalent to the Boreal Plateau of the Kern Canyon (Eocene Stage of Matthes in the Yosemite Valley region, as well as in the Upper San Joaquin drainage basin).

On the basis of a collection of eight Pliocene pollen floras, ranging in position from the present summit region of the Sierra Nevada out into the desert to the east, Axelrod and Ting (1960) make a convincing case for the following major episodes in the Late Cenozoic history of this part of the Sierra Nevada.

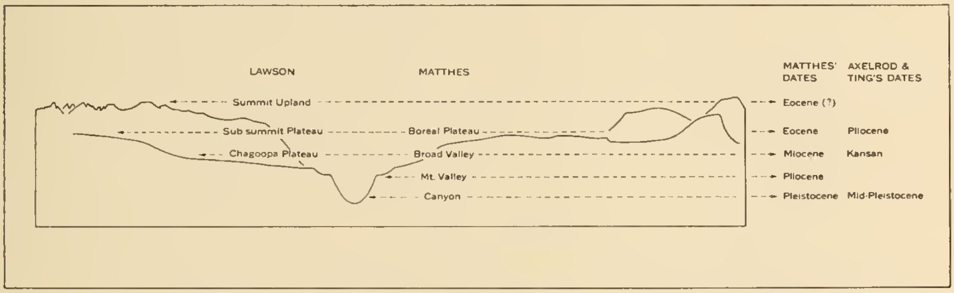


Fig. 1. Diagrammatic profile of upland surfaces of the southern Sierra, according to Lawson and Matthes, with their ages as estimated by (*a*) Matthes and (*b*) Axelrod and Ting. Profile after Matthes.

1. In the Late Pliocene a Sierran west-slope pine-fir forest covered the area east of the present Sierra Nevada, and sites that today are located in the alpine zone of the range crest.

2. This single vegetation-climatic zone in a region where today eight major climatic zones are represented indicates (*a*) that the Late Pliocene Sierran divide was low—low enough that it cast no significant rain shadow over the country to the east—and (*b*) the relief throughout this whole lowland region was slight—perhaps no more than 1,000 to 1,500 feet.

3. The presence of the moderate relief is substantiated by (*a*) the single vegetation-climatic zone, and (*b*) the widespread outpouring of basalt over much of the country east of the Sierra Nevada.

4. The principal uplift of the Sierra Nevada is Pleistocene. Axelrod and Ting point out that this idea was expressed by Lawson in 1904 and by Hopper in 1947, but is totally at variance with the views of Matthes.

5. A post-Lower Pleistocene major uplift of the range explains the presence of only three major glacial stages (McGee, Sherwin, Tahoe-Tioga). The range simply was not high enough to share in the earlier phases of the Pleistocene glaciation.

The correlation of glacial stages, east and west, has been in an unsatisfactory state for the past thirty years. Students of the literature on this subject will recall that on the east slope Blackwelder established four stages: in order from oldest to youngest, McGee, Sherwin, Tahoe, and Tioga. On the west slope Matthes recognized three: Glacier Point, El Portal, and Wisconsin. In an attempt to reconcile this difference, Blackwelder (1931, p. 918) proposed the tentative correlation shown in the accompanying tabulation (table A).

I agree with Axelrod and Ting (1960) that the Glacier Point and the Sherwin are not equivalent, but that the Glacier Point and the McGee very likely are. Tills of these last two stages are on upland surfaces far above the canyons scored deeply into the immediately adjacent mountains. The Sherwin and the El Portal, as well as moraines of the stages younger than these two, occupy positions within existing canyons or at their mouths.

TABLE A

Tentative Correlation Table of Glacial Stages

Iowa and Illinois	Sierra Nevada	
	East	Yosemite (Matthes)
Wisconsin	Tioga	Wisconsin
Iowan	Tahoe	
Illinoisan	— ? —	
Kansan	Sherwin	El Portal Glacier Pt.
Nebraskan	McGee	

LATE CENOZOIC HISTORY OF McGEE MOUNTAIN

McGee Mountain, as part of the Sierra Nevada, shares in the generalized history of the range outlined in the preceding paragraphs. It is, however, unusual in that moraines of all the glacial stages Blackwelder established for the eastern Sierra Nevada are present, and that the nature and amount of the Late Pleistocene diastrophism responsible for the uplift of the range is documented so clearly.

The basalt of McGee Mountain rests on an undulating surface of moderate relief which truncates the edges of the upturned hornfels and granitic rocks alike. In my view, this bare rock surface, with a predeformation gradient of around 200 feet per mile, was a pediment or some analogous piedmont surface. If we imagine the existing deep canyons to be filled in, this piedmont bench land would stretch north and south beyond its restricted modern limits and slope eastward and away from a low mountain range whose crest was perhaps only 1,500 to 2,000 feet higher than the pediment surface.

Following the flooding of the basalt over an extended sweep of the country eastward of the nascent Sierra Nevada, including the shoulder of McGee Mountain, the range began to rise. According to Axelrod and Ting (1961, p. 146), the uplift following the McGee glacial stage may have been 2,500–3,000 feet.

The glaciers of the McGee glacial stage had an approximate length of 7 to 9 miles, from the Sierran divide to the present-day location of their till on the McGee summit upland. How far they extended as piedmont glaciers beyond the front of the emerging range is conjectural, because the McGee till is now faulted down and out of sight below the alluviated plain of Long Valley. Axelrod (personal communication) does not believe they were as extensive as the glaciers of the succeeding Sherwin stage. Although there is little direct evidence here, farther south, according to him, on Coyote Flat near Bishop, McGee till grades into glaciofluviatile deposits; all are within the mountain block. Certainly, McGee glacial de-

posits are much more attenuated than Sherwin ones in the same relative locations along the Sierran front.

The Sierra Nevada was uplifted about 3,000 feet following the McGee glacial stage, and a canyon-cutting cycle was initiated. This resulted in the excavation of a large part of the canyons of McGee and Convict creeks, and the isolation of the

TABLE B

LATE CENOZOIC CHRONOLOGY AT McGEE MOUNTAIN

Local event	Sierran glacial equivalent	Central U.S. equivalent
Continued faulting and minor uplift; deposition of alluvial fans and cones....................	Recent	Recent
Glaciations within existing canyons.............	Tahoe and Tioga	Wisconsin
Eruption of rhyolitic pumice and obsidian; continued uplift of around 1,000 feet..............	....	Sangamon
Canyon deepening; valley glaciation............	Sherwin	Illinoian
Sierran uplift of approximately 3,000 feet; canyon cutting....................................	....	Yarmouth
Extensive upland glaciation.....................	McGee	Kansan
Uplift of the Sierra Nevada by about 2,500 feet; altitude too low for extensive glaciation.......	....	Aftonian and Nebraskan
Cutting of broad surface, now preserved as the summit upland of McGee Mountain; eruption of basalt....................................	Late Pliocene (?)	Late Pliocene (?)

upland shoulder on which the basalt and the McGee till are preserved. The canyons provided a channel down which the glaciers of the successive, post-McGee glacial stages (Sherwin, Tahoe, and Tioga) made their way, with each gaining less ground than its predecessor.

Between the time of the Sherwin and Tahoe glaciations, most of the country east of the Sierra Nevada, and between Mono Lake to the north and the central Owens Valley to the south, was inundated by an outpouring of rhyolitic pumice, sillar, and ignimbrite.

Presumably at about the same time, or at least in the interval preceding the Tahoe glaciation, the range gained possibly an additional 1,000 feet of altitude; probably in part by faulting, in part by warping.

Contemporaneously with the Tahoe glaciation, Long Valley held a short-lived lake that was drained away to the southward, possibly by headward growth and integration of the stream system that became the modern Owens River.

Faulting has continued into postglacial time, and alluvial fans and talus cones have continued to grow.

In summary form, the Late Cenozoic events at McGee Mountain, as I interpret them, are listed in sequence in the preceding table (table B), together with my best estimate of their probable time-equivalents in the central United States.

LITERATURE CITED

Axelrod, D. I.

1962. Post-Pliocene uplift of the Sierra Nevada, California. Geol. Soc. Amer., Bull., vol. 73, pp. 183–198.

Axelrod, D. I., and W. S. Ting

1960. Late Pliocene floras east of the Sierra Nevada. Univ. Calif. Publ. in Geol. Sci., vol. 39, pp. 1–118.

1961. Early Pleistocene floras from the Chagoopa surface, southern Sierra Nevada. Univ. Calif. Publ. in Geol. Sci., vol. 39, pp. 119–194.

Bateman, P. C.

1958. Geology of the Bishop 15-Minute Quadrangle, California. Unpublished Ph.D. dissertation, Univ. Calif., Los Angeles.

1961. Granitic formations in the east-central Sierra Nevada near Bishop, California. Geol. Soc. Amer., Bull., vol. 72, pp. 1521–1537.

Birman, J. H.

1957. Pleistocene glaciation in the upper San Joaquin drainage, Sierra Nevada. Unpublished Ph.D. dissertation, Univ. Calif., Los Angeles.

Blackwelder, Eliot

1930. Correlation of glacial epochs in western United States (abstract). Geol. Soc. Amer., Bull., vol. 42, p. 91.

1931. Pleistocene glaciation in the Sierra Nevada and Basin Ranges. Geol. Soc. Amer., Bull., vol. 42, pp. 865–922.

Chelikowsky, J. R.

1940. Tectonics of the rhyolite in the Mammoth embayment, California. Jour. Geol., vol. 48, pp. 421–435.

Curtis, G. H., J. F. Evernden, and J. Lipson

1958. The age determination of some granitic rocks in California by the potassium-argon method. Calif. State Div. Mines, Spec. Rept. 54. 16 pp.

Evernden, J. F., and G. H. Curtis

1962. The present status of potassium-argon dating of Tertiary and Quaternary rocks. Quaternaria, in press.

Gilbert, C. M.

1938. Welded tuff in eastern California. Geol. Soc. Amer., Bull., vol. 49, pp. 1829–1862.

1941. Late Tertiary geology southeast of Mono Lake, California. Geol. Soc. Amer., Bull., vol. 52, pp. 781–816.

Gilluly, James

1928. Basin and range faulting along the Oquirrh Range, Utah. Geol. Soc. Amer., Bull., vol. 39, pp. 1103–1130.

Hopper, R. H.

1947. Geologic section from the Sierra Nevada to Death Valley, California. Geol. Soc. Amer., Bull., vol. 58, pp. 393–432.

Hulin, C. D.

1931. Subsequent faulting in the Great Basin (abstract). Geol. Soc. Amer., Bull., vol. 42, p. 307.

Kesseli, J. E.

1941. Studies in the Pleistocene glaciation of the Sierra Nevada, California. II. Changes in the courses of some Pleistocene glaciers and their relation to interglaciation. Univ. Calif. Publ. in Geog., vol. 6, pp. 327–362.

Knopf, A., and E. Kirk

1918. A geologic reconnaissance of the east slope of the southern Sierra Nevada. U. S. Geol. Surv., Prof. Paper 110. 103 pp.

Lawson, A. C.

1904. The geomorphogeny of the upper Kern basin. Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, pp. 291–376.

MATTHES, F. E.

1930. Geologic history of the Yosemite Valley. U. S. Geol. Surv., Prof. Paper 160. 137 pp.

1937. The geologic history of Mt. Whitney. Sierra Club Bull., vol. 22, pp. 1–18.

1950. Sequoia National Park; a geological album. Univ. of Calif. Press, Berkeley and Los Angeles. 136 pp.

1960. Reconnaissance of the geomorphology and glacial geology of the San Joaquin basin, Sierra Nevada, California. U. S. Geol. Surv., Prof. Paper 329. 62 pp.

MAYO, E. B.

1934*a*. Pleistocene Long Valley Lake in eastern California. Science, n.s., vol. 80, pp. 95–96.

1934*b*. Geology and mineral deposits of Laurel and Convict basins, southwestern Mono County, California. Calif. Jour. Mines and Geol., vol. 30, pp. 79–87.

1937. Sierra Nevada pluton and crustal movement. Jour. Geol., vol. 45, pp. 169–192.

PAKISER, L. C., and M. F. KANE

1956. Gravity study of the structural geology of Owens and Long valleys, California (abstract). Geol. Soc. Amer., Bull., vol. 67, p. 1724.

PUTNAM, W. C.

1949. Quaternary geology of the June Lake district, California. Geol. Soc. Amer., Bull., vol. 60, pp. 1281–1302.

1960*a*. Origin of Rock Creek and Owens River gorges, Mono County, California. Univ. Calif. Publ. in Geol. Sci., vol. 34, pp. 221–280.

1960*b*. Faulting and Pleistocene glaciation in the east-central Sierra Nevada of California, U.S.A. Intl. Geol. Congress, Rept. of XXI Session, Norden, Pt. XXI, pp. 270–274.

RINEHART, C. D., and D. C. ROSS

1957. Geology of the Casa Diablo Mountain Quadrangle, California. U. S. Geol. Surv., Geologic Quadrangle Maps of the U. S., Map GQ 59.

RINEHART, C. D., D. C. ROSS, and N. K. HUBER

1959. Paleozoic and Mesozoic fossils in a thick stratigraphic section in the eastern Sierra Nevada, California. Geol. Soc. Amer., Bull., vol. 70, pp. 941–946.

RUSSELL, I. C.

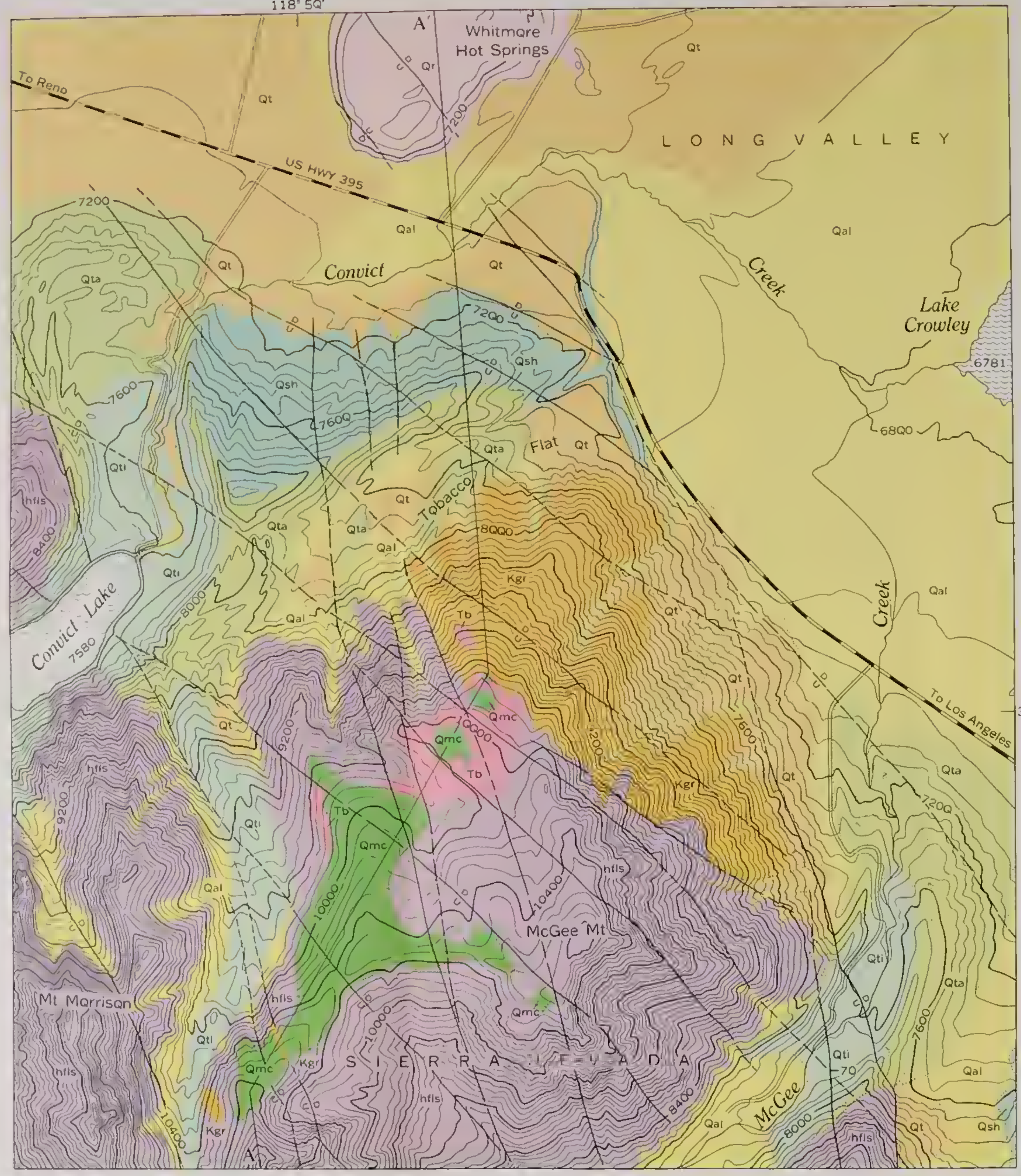
1889. Quaternary history of Mono Valley, California. U. S. Geol. Surv., Eighth Ann. Rept., Pt. II, pp. 26–394.

SCHUMACHER, GENNY, *et al.*

1959. The Mammoth Lakes Sierra. Sierra Club, San Francisco. 145 pp.

SPURR, J. E.

1905. The geology of the Tonopah mining district. U. S. Geol. Surv., Prof. Paper 42. 295 pp.



Base map from Mt. Morrison Quadrangle
U.S. Geological Survey, 1953

Geology mapped in 1959 by W. C. Putnam

EXPLANATION

QUATERNARY

Qal — Alluvium
Chiefly alluvium of talus cones and fans; lake beds adjacent to Lake Crowley.

Qt — Older Alluvium, Stream Terraces, Inactive Fans, & Cones
Boulders, cobbles, and gravel of terraces and dissected alluvial fans.

Qti — Tioga Till
Unweathered till of younger terminal and lateral moraines.

Qta — Tahoe Till
Slightly weathered till of earlier moraines related to existing glaciated canyons.

Qr — Rhyolite
Perlitic glass, obsidian, and interbedded pumice.

Qsh — Sherwin Till
Weathered till of eroded moraines at base of Sierra Nevada.

Qmc — McGee Till
Weathered till in marginal remnants on summit plateau of McGee Mt.

TERTIARY (?)

Tb — Basalt
Basaltic pyroclastic material and discontinuous flows on McGee Mt.

MAJOR ANGULAR UNCONFORMITY

CRETACEOUS

Kgr — Quartz Monzonite
Medium- to coarse-grained, locally porphyritic rock; some small, fine-grained dioritic inclusions.

LOWER PALEOZOIC

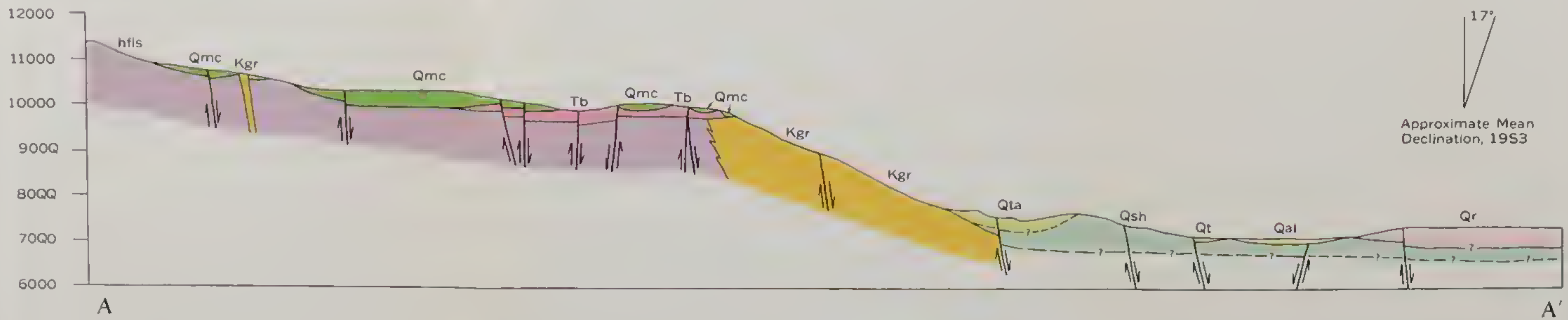
hfls — Metamorphic Rocks
Meta-sedimentary rocks, such as marble, quartzite, calc-silicate hornfels, shale hornfels and phyllite; minor amounts of tactite.

Fault
Dashed where approximately located: U, upthrown side; D downthrown side.

1 0 1 2 3 Miles

1 Q 1 2 3 4 Kilometers

Contour Interval 80 feet



GEOLOGIC MAP OF McGEE MOUNTAIN
MONO COUNTY, CALIFORNIA

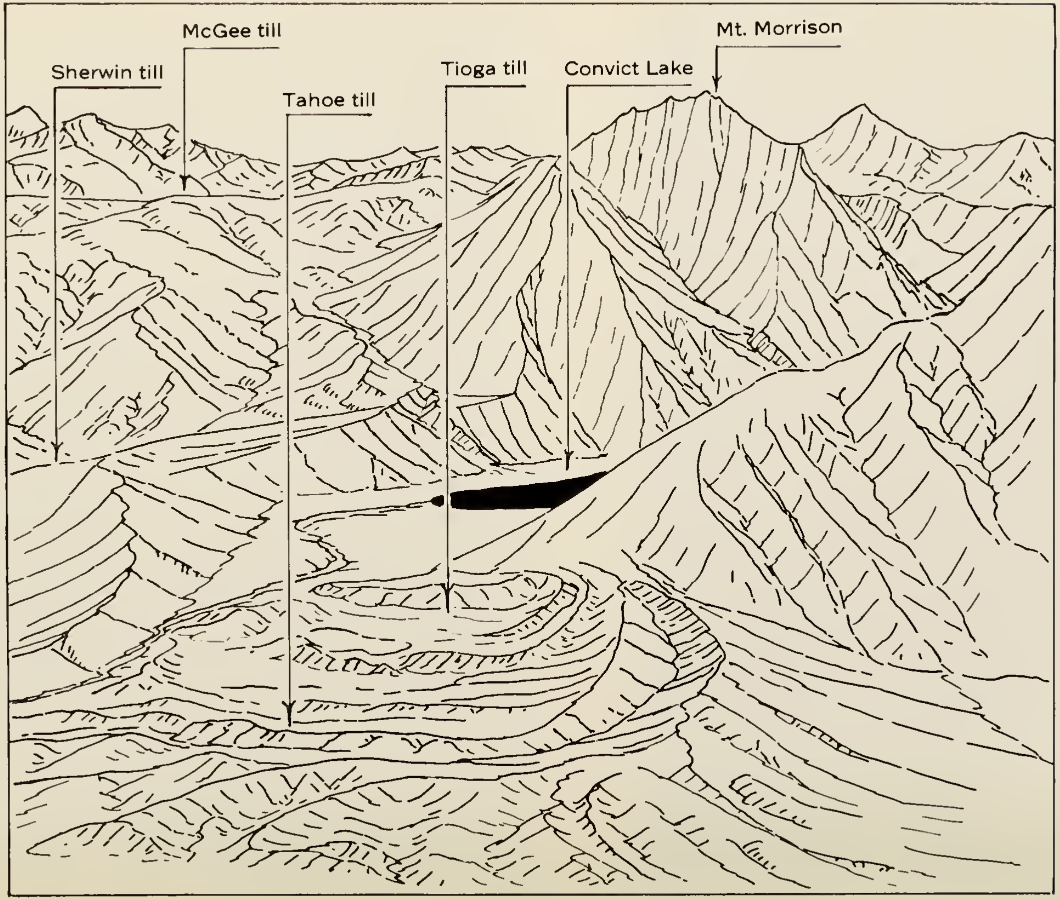
To accompany William C. Putnam, "Late Cenozoic Geology of McGee Mountain, Mono County, California." Univ. Calif. Publ. Geol. Sci. Vol. 40, No. 3

Map 1. Geologic map.

Williams & Heintz Map Corporation, Washington 27, D.C.

a. Polished surface of quartz monzonite boulder in McGee till. Photograph by G. P. Schumacher.

b. Large boulder in McGee till. Photograph by G. P. Schumacher.



Mt. Morrison
Sherwin till
McGee till
Tahoe till
Tioga till
Convict Lake

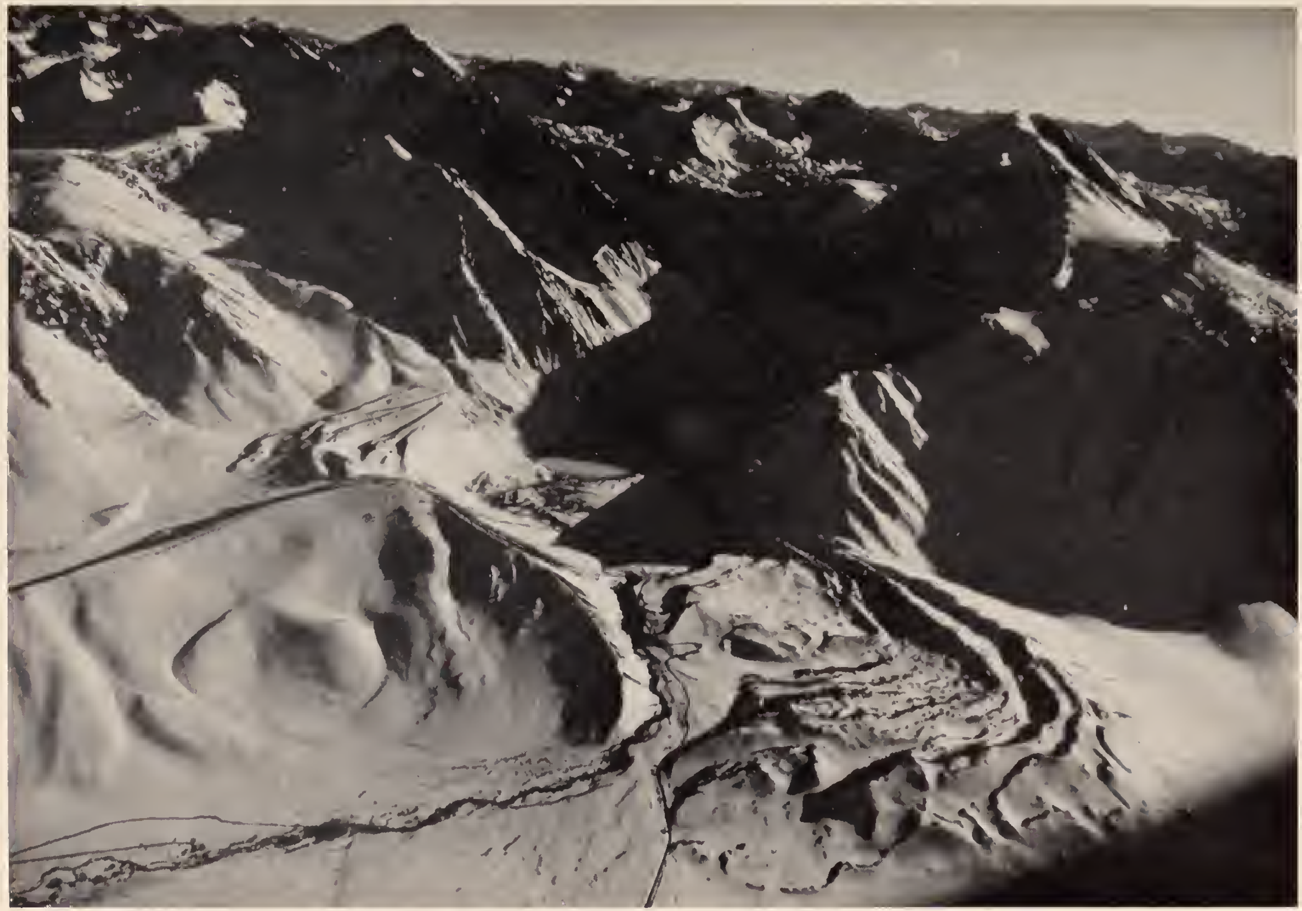
Aerial view of the mouth of Convict Canyon. Salient geomorphic features are indicated on the accompanying sketch. Photograph by R. von Huene.

a. Aerial view of Tahoe and Tioga moraines at mouth of McGee Canyon. Low fault scarp cutting the moraines is in central part of picture. Photograph by R. von Huene.

b. Deeply weathered boulders of McGee till. Projecting knobs are finer-grained dark inclusions. Photograph by T. C. Putnam.

Characteristic appearance of angular, quartz monzonite boulders in McGee till. Photograph by T. C. Putnam.

Characteristic appearance of angular, quartz monzonite boulders in McGee till.
Photographed by T. C. Putnam.



Aerial view of mouth of Convict Canyon. Tahoe and Tioga moraines form the crescentic loops in the foreground. Sherwin till underlies the large snow-covered ridge in the left foreground. McGee till rests on the upland near the left margin. Photograph by R. von Huene.